A method for correcting for tool face offset in directional drilling components, namely between a directional sensor reference point and a high side of a bent sub. Graduated markings applied on an outer surface of a UBHO sub containing the directional sensor and a reference marking on drill pipe indicating high side of the bent sub, or alternatively graduated markings applied to drill pipe relative to the high side of the bent sub and a reference marking on the outer surface of the UBHO, are together utilized to determine the tool face offset, which is then provided to a software program to permit the software program to then indicate a correct bent sub angular orientation to the directional drilling operator at surface. Bottom hole components utilizing graduated markings on one of such bottom hole components and having a reference marking on the other of the components, are also disclosed.
METHOD AND APPARATUS FOR
CALCULATING AND CORRECTING FOR
DIRECTIONAL DRILLING TOOL FACE
OFFSETS

FIELD OF THE INVENTION

[0001] This invention relates in general to directional drilling of wells which use directional sensors to indicate angular orientation of a well being drilled, and in particular to a method and apparatus for determining the angular offset between a directional sensor reference datum point and the high side of a bent sub when the directional sensor is threadably coupled to the bent sub.

BACKGROUND OF THE INVENTION AND
DESCRIPTION OF THE PRIOR ART

[0002] In commonly employed methods of drilling directional wells, a drill string includes a rotary drill bit on the lower end of the drill string, which rotary bit is connected to a downhole motor. The downhole motor is typically a positive displacement motor (PDM) or turbine style motor used to rotate the drill bit. For directional drilling, the drill motor is powered by drilling fluid pumped down the drill string, causing the drill bit to rotate relative to the drill string. When conventional straight-line drilling is desired the drill string along with the rotary bit is rotated from surface. When (as described below with regard to the “bent sub”) the angular direction of drilling is desired to be changed, the bent sub on the drill string is rotated from surface to a new angular position upon angular rotation of the drill string from 0-360°. The angular position of the bent sub is called a tool face. Tool face angles can be either magnetic or gravity based depending on which field the tool is oriented about.

[0003] In directional drilling the PDM is usually placed above the bent sub assembly, or may form part of a “bent sub” assembly, which forms a part of the bottom hole assembly (“BHA”) in a drill string. The bent sub typically comprises an inclined lower portion which is adapted to extend tangentially outwardly from a drill string at a precise angle, typically in the range of 1-3° and usually no greater than 5°. This is due to any angle greater than 5° causing undue stresses on the point of attachment of the bent sub to the drill string and causing likely failure of such attachment should a drill string with such a bent sub be rotated). Accordingly, due to the inclination of the bent sub, if the drill string is held stationary while the PDM rotates the drill bit, the bent sub will cause the well to be drilled in the direction of inclination of the bent sub. Such direction of drilling can be changed, as mentioned above, by rotating the drill string about an azimuth so as to point the inclined tool assembly to a new desired direction of drilling, and upon the powering of the PDM, thereby permitting the wellbore to be drilled in the desired direction of the selected azimuth.

[0004] Where PDM’s are used in directional drilling, namely to drill in various directions of the compass (i.e. azimuths) about a vertical well bore and at various inclined angles to a vertical wellbore, such as for example when drilling beside a lake it is desired to deflect the well from the vertical and under the lake so as to thereby permit the wellbore to extend and reach into a hydrocarbon-bearing formation under the lake, the correct deflection and direction of the wellbore being drilled can only be accomplished and maintained if real-time instantaneous knowledge of the current deflection and direction orientation of the PDM creating the wellbore is known.

[0005] To obtain such real-time knowledge of the direction which the bent sub is then pointing, typically a directional sensor device is indirectly or directly coupled (usually indirectly via a number of intervening subs, such as the PDM) to the bent sub, and placed downhole (as noted above, the PDM may or may not be part of the bent sub assembly). Encoded data from the directional sensor indicating the current BHA orientation is relayed to surface, and displayed to the drilling operator giving real-time knowledge of the directional orientation of the drill bit.

[0006] While a number of ways exist to convey such real-time data to surface, one method is via a “measurement-while-drilling” (“MWD”) mud pulser instrument located downhole in the drill string proximate the directional sensor. The mud pulser operates a poppet valve to provide Morse-code like mud pulses which travel through the ground or through the drill pipe and are received at surface, decoded, and displayed in a readout form (sometimes graphically) to the drilling operator, to allow him/her to immediately make any directional corrections in the wellbore being drilled.

[0007] Accordingly, the drill operator can steer the drill bit in a desired direction if the operator knows the direction of the tool axis (i.e. the angular direction of the directional sensor), and the particular orientation of the bent sub relative to the directional sensor.

[0008] When the drilling operator desires to drill straight, the drill string is rotated which in turn rotates the drill bit and that attached bent sub. Accordingly, due to the inclination of the bent sub, the resulting borehole slightly larger in diameter than the drill bit. Typically, when the operator desires to make a turn, the drill string is stopped from further rotation but at a known position with the high side of the bent sub (i.e the inclined side of the bent sub) inclined (i.e pointed) in the desired direction of drilling. Thereafter, pressurized drilling mud is supplied downhole to the PDM motor, to allow the rotary bit at the end of the bent sub to continue drilling in the desired direction, which generally will result in a smooth, gradually curved drilling path.

[0009] The portion of the drill string which houses the directional sensor (known in the industry as the Universal Bottom Hole Orienting sub or “UBHO sub”) is typically threadably coupled directly or indirectly to the bent sub portion of the drill string. Due to the nature of the threaded couplings and the fact that it is difficult to consistently align reference points on each of two coupled members to the same position due to different applied torques when making the threaded connection, different thread frictions, and different tolerances in thread machining, the angular orientation of a reference point on the UBHO sub housing and a reference point on the bent sub is non-uniform and varies with each BHA assembly. Thus the angular relationship of the UBHO sub (and a known angular reference point of the directional sensing tool contained therein) becomes unknown relative to the high side angular position of the bent sub to which the UBHO sub is coupled. This unknown angular misalignment is commonly termed “tool face offset”, and means (and is defined herein) as meaning the angular difference between a known angular reference point for the directional sensing tool, and the angular location of the high side of the bent sub which is rotatably coupled (directly or indirectly) to the directional sensing tool via the UBHO sub.
There currently are two methods for accounting for (or eliminating) tool face offset so that the angular position of a reference point for the directional sensing tool relative to the high side of the bent sub is thereby known or rendered known.

The first method is to eliminate the tool face offset, by configuring the directional sensing tool which is contained in the UBHO sub to permit it to rotate inside the UBHO sub until a known reference point for the direction sensing tool is aligned with the high side of the bent sub, and then securing the directional sensing tool in a fixed position to the UBHO by some means such as by set screws which are used to hold it in place once it is in the desired angular alignment. The main drawback of this first method is that the BHA may not initially be assembled as an integral unit which would allow the relative angular variances to be determined, as the component parts may be made by different manufacturers. This necessitates such operation being done in the field, often under harsh conditions, and when the BHA is suspended from the derrick is frequently difficult to do. Moreover, improper use in the field (overtightening, or stripping of set screws) may cause failure of such devices and the directional sensor in the UBHO thereby allowed to rotate relative to the UBHO and the reference point. Such causes the bent sub-directional tool angular relationship (tool face offset) to become lost and unknown, thus making steering of the drill string impossible in a directional drilling application. Such arrangement also makes it impossible (or at least very difficult) to have any extra connections (mechanical or electrical) between the directional sensing tool and the UBHO sub because it is never known how the MWD tool will be oriented in the UBHO sub. Any twisting of electrical connections between the directional tool and the UBHO can undesirably and in extreme cases result in the drill string becoming sensitive to small changes in the UBHO.

The second method, as illustrated in FIGS. 2 and 3 herein, is to have a UBHO sub supplied with a reference mark (a standard reference datum point) on the outside diameter thereof showing a known angular orientation of the directional sensing tool contained therein, which is previously fixedly secured to the UBHO. At the well site, the UBHO and coupled bent sub is suspended vertically in the oil derrick, with the reference mark being visible placed on the UBHO sub being visible. A wellhand places a visible vertical line extending vertically upwardly along the BHA from the high side of the bent sub up to and onto the UBHO, and then measures the circumferential distance from the vertical line which he has drawn on the UBHO sub to the reference mark appearing on the UBHO (say, for purposes of illustration, a measured distance “s”). Alternatively, instead of using a vertical line, the wellhand may, with the bent sub immediately before him/her, place a mark on the well casing (in which the BHA is to be lowered into and inserted) in alignment with the high side of the bent sub, and looking upwards to the UBHO suspended above him/her, place another mark on the periphery of the wellbore casing in vertical alignment with the reference mark on the UBHO suspended above. In both approaches the wellhand would then use the formula of:

\[
DAO = \frac{s}{\text{total circumference}} \times 360
\]

to calculate the “Drillers Assembly Offset” synonymously referred to as DAO or the tool face offset. This DAO can then be used to correct values received from the directional sensor indicating high side orientation for the bent sub, which would otherwise be inaccurate due to the tool face offset error.

As noted in U.S. Pat. No. 6,585,061, col. 2, lines 33-58, the disadvantage of this second method is that it is frequently subject to operator error. Specifically, the wellhand must:

(i) correctly measure the circumferential distance of separation and also the total circumference,

(ii) correctly calculate the angular magnitude of the tool face offset using the above formula; and lastly

(ii) correctly apply a negative or positive value, depending if the tool face offset means a clockwise or counterclockwise adjustment.

Mistakes in any one of the aforesaid steps can result in the drill operator drilling in the wrong direction and/or missing an intended hydrocarbon formation which can be an extremely costly.

To overcome the cumbersome nature of the second method and its proneness to operator error, U.S. Pat. No. 6,585,061 to a method for “Calculating Directional Drilling Tool Face Offsets” teaches a modification of the above-mentioned second method, where a particular type of directional sensor, namely a magnetic directional sensor or “magnetometer” is employed. A reference “tool face” for the magnetometer is known. When the BHA is suspended on the derrick, a wellhand places a visible vertical line on the BHA extending vertically upwardly from the high side of the bent sub up to the UBHO containing the magnetometer. Thereafter the wellhand places a calibrating frame containing a magnetic field, with means thereon indicating the direction of the magnetic field of such calibrating frame, and such frame is placed in proximity to the magnetometer with the means indicating the direction of the magnetic field of the calibrating frame placed in alignment with the vertical marking on the BHA. Such thereby causes the magnetometer within the UBHO to indicate a new reference point aligned with such BHA line, and thereby determine a signed (±) number which may be added to the directional sensor original reference “tool face” to indicate the correct alignment of the bent sub high side.

Disadvantageously, however, as regards the method and apparatus of U.S. Pat. No. 6,585,061 as noted at col. 5, lines 66 to col. 6, line 12, the magnetic field on the calibrating frame must be strong enough to overcome the time-varying magnetic field fluctuations located in the vicinity of the drilling rig. However, if the magnetic field generated by the calibrating tool (ie frame containing one or more magnets) is too strong, it will cause the magnetometer (directional sensor) to saturate so that it does not provide an accurate reading of the direction of the magnetic field. It is frequently difficult to achieve the appropriate balance between adequate strength of magnetic field on the calibrating tool, but being insufficient in strength so as to not cause the magnetometer to become saturated. Such imbalance frequently results in errors in determining tool face offset using the method and apparatus of U.S. Pat. No. 6,585,061.

U.S. Pat. No. 7,814,988 entitled “System and Method for Determining the Rotational Alignment of Drill String Elements” teaches a method for determining the relative rotational position of two or more elements in a drill string being conveyed into a wellbore, wherein a sensor is used to determine the location of a reference objects placed on each of the two elements whose relative angular relationship to each other is desired to be determined. Based on measure-
ments made by the sensor, a processor determines the rotational or angular offset between the two or more elements on the drill string.

[0021] Disadvantageously, however, the system and method of U.S. Pat. No. 7,814,988 requires a relatively costly sensor, which must be located in proximity to each of the elements whose relative orientation is desired to be determined, and whose output may be difficult to obtain or at least require implementing an automated means to obtain it which adds complexity, and in addition requires the provision of reference objects on each of the two elements thereby adding to the cost of each of such elements.

[0022] U.S. Pat. No. 4,181,014 entitled “Remote Well Signaling Apparatus and Methods” comments inter alia on the problem of unknown angular relationship between a wellbore directional sensor (or sensors) and a bent sub, and teaches at col 3, lines 24 and FIG. 3 that markings on the connected parts may be provided to enable measurement of the relative rotary positions of the instrument body and bent sub, to thus indicate a rotary adjustment which may be made to the directional sensors to achieve proper alignment. It is further disclosed that the required necessary adjustment is then done by way of a screwdriver, as taught at col. 7, lines 45-55, col. 13, lines 49-50, and col. 14, lines 4-27. Disadvantageously, however, no disclosure is made with regard to the manner of markings, and in particular any manner with regard to arranging the markings relative to each other, nor any method to avoid operator error in improperly assigning a negative adjustment when a positive adjustment is necessary, or vice versa. As well, the disclosed method requires screwdriver adjustment of each of the pair of sensors to eliminate tool face offset, which is a cumbersome procedure.

SUMMARY OF THE INVENTION

[0023] In order to overcome the aforesaid disadvantages and shortcomings in the methods and systems of the prior art, a first broad aspect the present invention comprises a method for determining and correcting for any angular offset between a directional sensor reference point (tool face) and a high side of a bent sub assembly when said directional sensor and said bent sub are coupled together.

[0024] Specifically, in a broad aspect such method comprises the steps of:

[0025] (i) utilizing

[0026] (a) a series of graduated markings applied on an outer surface of a housing member containing said directional sensor each of identifiable but individually different angular relation to a reference point of said directional sensor, and a reference marking on a bent sub assembly to which said housing member is threadably connected indicative of high side angular location of said bent sub assembly; or

[0027] (b) a series of graduated markings applied on a bent sub assembly in known relation to said high side angular location of said bent sub assembly, and a reference marking on said housing member in known relationship to said reference point of said directional sensor;

to determine angular offset of said directional sensor reference point relative to said high side of said bent sub; and

[0028] (ii) providing said determined angular offset to a software program to permit said software program to adjust directional sensor output received from said directional sensor to then indicate a correct bent sub angular orientation.

[0029] The particular software program used for displaying the orientation of the rotary bit at the end of the BHA and to which is supplied the tool face offset in accordance with the present invention, may be any one of the directional drilling software programs available which utilize a tool face offset input to correct directional sensor output, such as BTR Interface™ provided by Bench Tree Group LLC of Georgetown Tex., NaviTrak™ supplied by Baker Hughes Inttec, GUIDE MWD Surface System™ supplied by Toleq Inc. of Cedar Park, Tex., DrillWELL™ provided by Nuvoco Directional & Horizontal Services Inc. of Caglary, Alberta, XXT DRT™ supplied by XXT Inc. of Santa Clara, Calif., Sure Shot Control Center™ supplied by APS Technology of Walingford, Conn., qMWD PCT™, currently supplied by General Electric Inc. but originally supplied by Tensor Inc. of Austin Tex., Navigator™ supplied by Geolink Inc. of Aberdeen, Scotland but now owned by General Electric Company, and/or BSI Tech, a tradename for directional drilling software formerly supplied by Blue Star Tools Inc. of Calgary, Ab, now owned by General Electric Company.

[0030] Advantageously, such above method of the present invention renders unnecessary any additional hardware, such as one or more sensors as taught in U.S. Pat. No. 7,814,988, or any adjustment in the field to the bent sub, UBHO or directional sensor as taught in U.S. Pat. No. 4,181,014, nor does it require any calibrating tool such as disclosed in U.S. Pat. No. 6,585,061.

[0031] In order to ensure that readings from the graduated markings on either the UBHO sub housing or bent sub assembly are correctly utilized to provide a positive or negative tool face offset correction, in a first refinement of the above method where a series of graduated markings are circumferentially applied on an outer surface of a housing member (UBHO sub) containing said directional sensor, the method of the invention provides for utilizing numerical gradations associated with said graduated markings which increase progressively positively in an angular direction from a zero position indicative of said reference marking and increase progressively more negatively in an opposite angular direction from said zero position, and thereafter utilizing a reference marking applied said bent sub assembly indicative of the high side angular orientation of said bent sub, to determine the magnitude of positive or negative angular offset of said directional sensor reference point relative to said high side of said bent sub; and thereafter providing such determined offset to a software program to permit said software program to then correct sensed directional sensor orientation by said angular determined offset to indicate a correct bent sub angular orientation.

[0032] In a second alternative embodiment which likewise ensures that readings from the graduated markings are correctly utilized to provide a positive or negative tool face offset correction, a series of graduated markings circumferentially applied about an outer periphery of a bent sub assembly wherein numerical gradations associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said high side angular location of said bent sub and increase progressively negatively in an opposite angular direction from said zero position, and a reference marking on the housing containing the directional sensor, are utilized to determine the magnitude
of positive or negative angular offset of said directional sensor reference point relative to said high side of said bent sub; and such determined offset is thereafter provided to a software program to permit said software program to then correct sensed directional sensor orientation by said angular determined offset to indicate a correct bent sub angular orientation.

In a further broad embodiment of the present invention, a bottom hole assembly for use in directional drilling is provided, wherein one or more of the above methods may be employed to obtain tool face offset.

Specifically, in a further broad embodiment of the present invention, a bottom hole assembly for use in directional drilling is provided, comprising:

(i) a housing member containing a directional sensor for sensing orientation of the drill string;

(ii) a bent sub assembly threadably coupled to said housing member;

(iii) a series of graduated markings circumferentially applied on said bent sub assembly in known relationship to a high side of said bent sub assembly, wherein numerical graduations associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said high side angular location of said bent sub and increase progressively negatively in an opposite angular direction from said zero position, and

(b) a reference marking on said housing member indicative of said directional sensor reference point.

Alternatively, a bottom hole assembly for use in directional drilling is provided, comprising:

(i) a housing member containing a directional sensor for sensing orientation of the drill string;

(ii) a bent sub assembly threadably coupled to said housing member;

(iii) a series of graduated markings applied on an outer surface of a housing member containing said directional sensor, wherein numerical graduations associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said reference point and increase progressively negatively in an opposite angular direction from said zero position, and

(b) a reference marking on said bent sub assembly indicative of bent sub high side angular location.

In a further aspect of the invention, the invention comprises an orienting sub, comprising:

(i) a housing member containing a directional sensor for sensing orientation of the drill string, said directional sensor fixedly secured to said housing member sub in known angular relation to said graduated markings thereon; and

(ii) a series of graduated markings applied circumferentially on an outer surface of a housing member containing said directional sensor, wherein numerical values associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said reference point and increase progressively negatively in an opposite angular direction from said zero position, adapted to allow determination of angular offset of said directional sensor reference point relative to a high side of a bent sub assembly.

In a still further aspect of the invention, the invention comprises a bent sub assembly for use in directional drilling, comprising:

(i) thread coupling means to allow threadable coupling to an orienting sub containing a directional sensor;

(ii) a series of graduated markings applied circumferentially on an outer surface of said bent sub assembly, wherein numerical values associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of a high side of said bent sub and increase progressively negatively in an opposite angular direction from said zero position, adapted to allow determination of angular offset of said high side from an orienting directional sensor reference point on said orienting sub when threadably connected thereto.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and permutations and combinations of the invention will now appear from the above and from the following detailed description of a few particular embodiments of the invention taken together with the accompanying drawings, each of which are intended to be non-limiting and merely illustrative, in which:

FIG. 1a is a side elevation view and partial cross section of a first embodiment of a bottom hole assembly in a wellbore;

FIG. 1b is a frontal (non-cross sectional) view of the embodiment of the bottom hole assembly of the present invention shown in FIG. 1a, taken in direction of arrow “N”;

FIG. 1c is a frontal (non-cross sectional view) of an alternative embodiment of the bottom hole assembly of the present invention;

FIG. 2 (prior art) is an illustration of a first step in a method of the prior art for determining tool face offset, showing a bottom hole assembly being lowered from a derrick into a wellbore and a line indicating the high side of the bent sub being applied to the drill string;

FIG. 3 (prior art) is an illustration of a second step in the prior art method of the prior art for determining tool face offset;

FIG. 4 is an illustration, looking downwardly on the bottom hole assembly (“BHA”), showing a tool face offset “R”, between the directional tool datum reference point RP of the directional sensor unit, and the high side HS of a bent sub assembly;

FIG. 5 is an illustration, looking downwardly on the bottom hole assembly (“BHA”), showing a tool face offset “Q”, between the directional tool datum reference point RP and the high side HS of a bent sub;

FIG. 6 is a side view on a bottom hole assembly (“BHA”) showing an orienting sub connected to a bent sub assembly, wherein the bent sub assembly has a series of graduations circumferentially applied thereto, and the orienting sub has a reference point thereon in known relation to a reference data point of a directional sensor contained in said orienting sub;

FIG. 7 is a view looking in direction of arrow “S” of FIG. 6;

FIG. 8 is a side view on a bottom hole assembly (“BHA”) showing an orienting sub connected to a bent sub assembly, wherein the orienting sub has a series of gradu-
tions circumferentially applied thereto, and the bent sub has a reference mark applied thereto in known relation to the high side of the bent sub;

**[0061]** FIG. 9 is a view looking in direction of arrow “T” of FIG. 8;

**[0062]** FIG. 10 is a side view on a bottom hole assembly (“BHA”) showing an orienting sub connected to a bent sub assembly, wherein the bent sub assembly has a series of graduations circumferentially applied thereto in the form of letters of the alphabet;

**[0063]** FIG. 11 is a view looking in direction of arrow “S” of FIG. 10;

**[0064]** FIG. 12 is a side view on a bottom hole assembly (“BHA”) showing an orienting sub connected to a bent sub assembly, wherein the orienting sub has a series of graduations circumferentially applied thereto in the form of letters of the alphabet;

**[0065]** FIG. 13 is a view looking in direction of arrow “T” of FIG. 12;

**[0066]** FIG. 14 is a side view on another embodiment of a bottom hole assembly (“BHA”), showing an orienting sub connected to a bent sub assembly, wherein the bent sub assembly has a series of numerical graduations circumferentially applied thereto which increase progressively positively in an angular direction from a zero position indicative of a high side angular location of said bent sub and increase progressively negatively in an opposite angular direction from said zero position, and the orienting sub has a reference point thereon in known relation to a reference datum point of a directional sensor contained in said orienting sub;

**[0067]** FIG. 15 is a view on arrow “U” of FIG. 14;

**[0068]** FIG. 16 is a view on arrow “V” of FIG. 15;

**[0069]** FIG. 17 is a side view on another embodiment of a bottom hole assembly (“BHA”), showing an orienting sub connected to a bent sub assembly, wherein the orienting sub has a series of numerical graduations circumferentially applied thereto which increase progressively positively in an angular direction from a zero position indicative of a reference datum point for the directional sensor contained therein, and increase progressively negatively in an opposite angular direction from said zero position, and the bent sub has a reference point thereon in known relation to a high side thereof;

**[0070]** FIG. 18 is a view on arrow “W” of FIG. 17; and

**[0071]** FIG. 19 is a view on arrow “Z” of FIG. 18.

**DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS**

**[0072]** FIG. 1a shows a typical BHA 10 of the present invention used in directional drilling of wellbores 12, having a bent sub assembly 14, a rotary drill bit 16, and a PDM motor 18 coupled to the rotary bit 16. The bent sub assembly 14 is threadably coupled by thread coupling 20, through the intermediary of the PDM motor 18, and further intervening sub 19 to a UBHO sub 22, which is in turn coupled upwell to drill pipe (not shown). UBHO sub 22 contains therein a muleshoe 26 in which is located directional sensor unit 24 of the type commonly used in directional drilling. The PDM motor 18 may be included in the bent sub assembly 14, or may be located in proximity to the UBHO assembly 22.

**[0073]** As advantageously seen in FIG. 1b (a non-cross-sectional view taken in the direction of arrow “N” of FIG. 1a), such shows one embodiment of the invention having a series of graduations 50 on the UBHO sub 22, in known angular relation to a reference datum point RP of the directional sensor 24. Such graduations 50 are used in the manner hereinafter described to determine in relatively error-free manner the existing tool face offset between high side HS of bent sub assembly 14, and the RP of directional sensor unit 24.

**[0074]** FIG. 1c depicts a non-cross-sectional view of another embodiment of the BHA 10 of the present invention, likewise having a plurality of graduations 50, but such instead located instead about the outer periphery of the bent sub assembly 14 a spaced distance downhole from the directional sensor unit 24.

**[0075]** Directional sensor unit 24 is typically securable to the UBHO sub 22 at “factory” (and not in the field or at the well site) by set screws 15 which engage the muleshoe 26 in the UBHO sub 22, which when secured prevents angular rotation of directional sensor 24 relative to the UBHO sub 22.

**[0076]** Directional sensor 24 possesses an angular datum reference point RP, from which it is able to determine angular orientation relative to the earth’s gravitational field or magnetic field. A drilling operator, however, when directionally drilling, need know the orientation of the high side HS of the bent sub assembly 14, in order to know which way the bent sub assembly 14 (and thus the rotary drill bit 16) is pointing, in order to effectively “steer” the drill bit 14 and thus direct in which direction the directional drilling will proceed.

**[0077]** Problematically, however, in BHA’s of the prior art (see FIGS. 2 & 3) which lack graduated markings 50 which extend around the periphery of either the bent sub assembly 14 or the UBHO sub 22, due to the nature of the threaded coupling 20 threadably connecting bent sub assembly 14 to UBHO sub 22 resulting in inconsistent extent of rotational engagement between the two components, the angular relationship between bent sub assembly 14 and UBHO sub 22 and the reference point RP of the directional sensor 24 therein is non-uniform accordingly varies from one BHA assembly 10 to another.

**[0078]** In order to determine resulting tool face offset in the prior art, and with reference to FIGS. 2 & 3 (PRIOR ART), the prior art method of determining the tool face offset R or Q (see FIG. 5) between an angular reference point RP in regard to the directional sensor 24 in UBHO sub 22 and the high side (HS) of the bent sub assembly 14 is as follows. An externally visible reference position-indicating mark RP is placed on the exterior of UBHO sub 22, indicating an angular reference point RP of the directional sensor 24. The BHA assembly 10 is mated by the derrick (not shown) in a vertical position prior to inserting down wellbore casing 40, as shown in FIG. 2. A mark (vertical line) 42 is drawn on wellbore casing 40 in line with the high side HS of bent sub assembly 14, as shown in FIG. 2. The derrick lowers the BHA assembly 10 into wellbore casing 40, to a level where the reference position indicating mark RP is level with the top of the wellbore casing 40, and a further mark 44 is placed on the wellbore casing 40. The tool face offset “R” in angular degrees (see FIG. 4) is then determined using the formula:

\[
tool\ face\ offset = \frac{s}{360} \times 360
\]

where ‘s’ is the circumferential distance separating mark 42 from further mark 44, and “C” is the total circumference of wellbore casing 40.
Such tool face offset \( R \) may then be supplied to a computer program of the type disclosed above, in order to allow the computer program to adjust for the angular offset between the reference point \( RP \) and the high side HS of the bent sub assembly \( 14 \) and make the required correction by subtracting or adding the appropriate value.

Disadvantageously, for the reasons set out in the Background of the Invention, this prior art method currently being used requires the wellhand to measure, calculate using the above formula, and thereafter determine (in negative or positive value) a tool face offset. It is accordingly fraught with a risk of inadvertent error, which can result in mis-drilled wellbores 12.

Advantageously, as shown in FIGS. 16 & 1c, and further in FIGS. 6 & 7, FIGS. 8 & 9, FIGS. 10 & 11, FIGS. 12 & 13, FIGS. 14-16 and FIGS. 17-19, each of the embodiments shown therein illustrate variations of the present invention, each providing graduations \( 50 \) as more fully described herein and whose purpose is further explained herein, to provide a BHA 10 and method to eliminate the susceptibility to errors when calculating tool face offset.

Specifically, in the embodiment shown in FIGS. 6 & 7 a bent sub assembly \( 14 \) is provided with a series of graduated markings \( 50 \) circumferentially extending around a periphery thereof, in known relation to the angular location of the high side HS of the bent sub assembly \( 14 \). In the embodiment shown in FIGS. 6 & 7, associated with such graduated markings \( 50 \) are associated numbers \( 52 \) from 0-360\(^\circ\), in increments of 5\(^\circ\) on the bent sub assembly \( 14 \). Alternatively, associated with each of the graduated markings \( 50 \) may be unique symbols or letters \( 54 \), as shown in FIGS. 10 & 11, which in the example shown in FIGS. 10 & 11, likewise divide the circumference of bent sub assembly \( 14 \) into a series of uniform angular increments each denoting 10\(^\circ\), by providing for thirty-six letters \( 54 \) in a sequence extending from A-Z and further from AA to AZ, as shown. Other individual letter sequences, using more letter sequences may be used, if accuracy greater than 10\(^\circ\) increments are desired. Alternatively, individual symbols could be used, and provided to software program (not shown) which further has a table of concordance to convert such symbol or letter \( 54 \) into an associated angular tool face offset \( R \) or \( Q \). The graduations \( 50 \) on the bent sub assembly \( 14 \) may be placed a spaced distance from the UBHO sub \( 22 \) and in proximity to the tool bit \( 16 \) as shown in FIG. 1c, or if there is no intervening threaded connecting sub assemblies between the bent sub assembly \( 14 \) and the UBHO sub \( 22 \), may be placed on the bent sub assembly \( 14 \) in close proximity to the UBHO sub \( 22 \), as shown in FIGS. 6 & 7, FIGS. 8 & 9, FIGS. 10 & 11, FIGS. 12 & 13, FIGS. 14-16 and FIGS. 17-19.

A reference point RP is provided on exterior of UBHO sub \( 22 \), indicative of the location of the internal reference angular datum of the directional sensor \( 24 \) contained in the UBHO sub \( 22 \). A line \( 25 \) may be made down the side of the BHA assembly \( 10 \), aligned with the RP of the directional sensor in the UBHO sub \( 22 \), as shown in FIG. 1c, if there is intervening threadably-connected sub assemblies \( 19 \), as shown in FIG. 1c, between the UBHO sub \( 22 \) and the bent sub assembly \( 14 \). Alternatively, no line \( 25 \) need be used to determine tool face offset \( R, Q \) if the bent sub assembly \( 14 \) may be directly threadably connected to UBHO sub \( 22 \), as shown in FIGS. 6 & 7, FIGS. 8 & 9, FIGS. 10 & 11, FIGS. 12 & 13, FIGS. 14-16 and FIGS. 17-19.

In the embodiment shown in FIGS. 6 & 7 a wellhand may then simply read the associated numerical number \( 52 \) appearing immediately below mark \( RP \) as shown in FIG. 7, or the letter \( 54 \) immediately below mark \( RP \) as shown in FIG. 11, in order to obtain the tool face offset \( R \) associated with such BHA assembly \( 10 \). Thereafter, in the case of a number \( 52 \) (ie a degree reading) the wellhand may simply supply the associated value to a computer software program being used by the drilling operator, which may then correct values received from the directional sensor \( 24 \), to ensure that the direction indicated by such computer software is the true direction in which the bent sub assembly \( 14 \) is then pointing.

In the case of a letter \( 54 \) (see FIG. 11), the wellhand reads the letter \( 54 \) immediately below the mark \( RP \) (or in the case of FIG. 1c, the letter which is aligned with line \( 25 \)), and then supplies that letter \( 54 \) to a computer software program being used by the drilling operator, which may then correlate such letter \( 54 \) using a table of concordance (not shown) stored within said computer program to an associated tool face offset value \( R \), and then use such value to correct (by subtraction or addition thereto) the angular direction values received from the directional sensor \( 24 \), to ensure that a direction indicated by such computer software as to the angular direction of the high side HS of the bent sub assembly \( 14 \) is the true angular direction in which the bent sub assembly \( 14 \) is then pointing.

In an alternative embodiment of the invention, instead of the graduated markings \( 50 \) and associated numbers \( 52 \) or letters \( 54 \) being provided on bent sub assembly \( 14 \), such graduated markings may be provided instead on the UBHO sub \( 22 \) as shown FIGS. 8 & 9 and in FIGS. 12 & 13. In such embodiment, a series of graduated markings \( 50 \) are circumferentially provided on an outer surface of UBHO sub \( 22 \), each of identifiable but individually different angular relation to a reference point RP of directional sensor \( 24 \) contained in UBHO sub \( 22 \). A reference marking HS is provided on bent sub assembly \( 14 \) to which the UBHO sub \( 22 \) is threadably connected, which is indicative of a high side angular location HS of said bent sub assembly \( 14 \). Alternatively, if bent sub assembly \( 14 \) is not directly threadably coupled to UBHO sub \( 22 \), as shown in FIG. 1b a line HS may be drawn on the side of BHA assembly \( 10 \) indicative of the high side angular location HS of bent sub assembly \( 14 \), which line HS may be extended upwardly (by drawing or by visual sighting) along the side of BHA \( 10 \) to the graduations \( 50 \) appearing on the UBHO sub \( 22 \), as shown in FIG. 1b.

A wellhand may then simply read the associated numerical number \( 52 \) appearing immediately above mark \( HS \) as shown in FIG. 8, or the letter \( 54 \) immediately above mark \( HS \) as shown in FIG. 12 in order to obtain the tool face offset \( R \) associated with such BHA assembly \( 10 \). Again, in the case of a number \( 52 \) (ie a degree reading) the wellhand may then simply supply the associated value to a computer software program being used by the drilling operator, which may then correct values received from the directional sensor \( 24 \), to ensure that the direction indicated by such computer software is the true direction in which the bent sub assembly \( 14 \) is then pointing. In the case of a letter \( 54 \) (see FIGS. 12 & 13), the wellhand may simply read the letter \( 54 \) immediately above the mark \( HS \), and then supply that letter \( 54 \) then supply the associated value to a computer software program being used by the drilling operator, which may then correlate such letter \( 54 \) using a table of concordance to an associated tool face offset value \( R \), and then use such value to correct angular direction values received from the directional sensor \( 24 \) to
ensure that a direction indicated by such computer software as to the angular direction of the high side HS of the bent sub assembly 14 is the true angular direction in which the bent sub assembly 14 is then pointing.

[0088] In an alternative embodiment shown in FIGS. 14-16, a series of graduated markings 50 are circumferentially provided on a bent sub assembly 14. Numerical values 52 associated with said graduated markings 50 increase progressively positively in a clockwise angular direction from a zero position indicative of said high side angular location HS of said bent sub assembly 14 and increase progressively negatively in an opposite (counterclockwise) angular direction from said zero position. A reference marking RP is provided on an outer surface of UBHO sub 22 containing directional sensor 24 indicative of an angular reference point for said directional sensor 24.

[0089] A wellhand may then read the associated negative or positive numerical value 52 appearing immediately below mark RP as shown in FIG. 15, in order to obtain the tool face offset R associated with such D1A assembly 10. Thereafter, the wellhand may then supply the associated negative or positive value 52 to a computer software program being used by the drilling operator, which may then correct values received from the directional sensor 24 using such value 52 to ensure that the direction indicated by such computer software is the true direction in which the bent sub assembly 14 is then pointing.

[0090] Alternatively, as shown in FIGS. 17-19, a series of graduated markings 50, having associated negative or positive values 52 depending on the angular direction (clockwise or counterclockwise) of tool face offset R or Q, may be circumferentially provided on UBHO sub 22. A reference marking HS is provided on an outer surface of bent sub assembly 14 indicative of the high side HS of bent sub assembly 14. Again, the wellhand may then read the positive or negative numerical value 52 appearing above line HS, and thereafter supply the associated negative or positive value 52 to a computer software program being used by the drilling operator, which may then correct values received from the directional sensor 24 using such value 52 to ensure that the direction indicated by such computer software is the true direction in which the bent sub assembly 14 is then pointing.

[0091] The foregoing description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to those embodiments will now be readily apparent and occur to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein, but is to be accorded the full scope consistent with the claims.

[0092] Where reference to an element in the singular, such as by use of the article “a” or “an”, such is not intended to mean “one and only one” unless specifically so stated, but rather “one or more”. Reference to “below” shall be with respect to the orientation of items in a wellbore shown in FIGS. 1-19 attached hereto.

[0093] No element of any of the claims appended to this application is to be construed under the provisions of 35 USC §112, sixth paragraph as being limited to the particular embodiment shown, unless the claim element is expressly recited using the exact phrase “means for” or “step for”.

[0094] For a complete definition of the invention and its intended scope, reference is to be made to the summary of the invention and the appended claims read together with and considered with the disclosure and drawings herein.

1. A method for determining and correcting for any angular offset between a directional sensor reference point and a high side of a bent sub assembly when said directional sensor and said bent sub are coupled together, comprising the steps of:
   (i) utilizing
      (a) a series of graduated markings applied on an outer surface of a housing member containing said directional sensor each of identifiable but individually different angular relation to a reference point of said directional sensor, and a reference marking on a bent sub assembly to which said housing member is threadably connected indicative of a high side angular location of said bent sub assembly; or
      (b) a series of graduated markings applied on said bent sub assembly in known relation to said high side of said bent sub assembly, and a reference marking on said housing member in known relationship to said reference point of said directional sensor,
   to determine via said graduated markings an angular offset of said directional sensor reference point relative to said high side of said bent sub assembly; and
   (ii) providing said determined angular offset to a software program to permit said software program to adjust directional sensor output received from said directional sensor to then indicate a correct bent sub assembly angular orientation.

2. A method for determining and correcting for an angular offset between a directional sensor reference point and a high side of a bent sub assembly when said directional sensor and said bent sub are coupled together, comprising the steps of:
   (i) utilizing
      (a) a series of graduated markings circumferentially applied on an outer surface of a housing member containing said directional sensor, wherein individual numerical values associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said reference point and increase progressively negatively in an opposite angular direction from said zero position, and
      (b) a reference marking applied on a bent sub assembly which is indicative of bent sub assembly high side angular location,
   to determine positive or negative angular offset of said directional sensor reference point relative to said high side of said bent sub assembly; and
   (ii) providing said determined angular offset to a software program to permit said software program to then correct sensed directional sensor orientation by said angular offset to indicate a correct bent sub angular orientation.

3. A method for determining and correcting for an angular offset between a directional sensor reference point and a high side of a bent sub when said directional sensor and said bent sub are coupled together, comprising the steps of:
   (i) utilizing
      (a) a series of graduated markings circumferentially applied on a bent sub assembly, wherein numerical values respectively associated with said graduated markings increase progressively positively in an
angular direction from a zero position indicative of said high side angular location of said bent sub assembly and increase progressively negatively in an opposite angular direction from said zero position, and
(b) a reference marking applied on an outer surface of a housing member containing said directional sensor indicative of an angular reference point for said directional sensor;
to determine positive or negative angular offset of said directional sensor reference point relative to said high side of said bent sub assembly; and
(ii) providing said angular offset to a software program to permit said software program to then correct sensed directional sensor orientation by said angular offset to indicate a correct bent sub angular orientation.
4. A method for directional drilling of a well with a drill string which utilizes a directional sensor and possesses a bent sub assembly, comprising the steps of:
(i) securing a housing containing said directional sensor to said bent sub assembly;
(ii) utilizing a series of graduated markings circumferentially applied on an outer surface of said housing member containing said directional sensor which markings individually bear a known relation to a reference point for said directional sensor, and a reference marking on said bent sub assembly in known relation to a high side angular location of said bent sub assembly; or utilizing a series of graduated markings applied on said bent sub assembly each in known angular relation to a high side angular location of said bent sub assembly, and a reference marking on said housing member indicative of said directional sensor reference point;
to determine angular offset of said directional sensor reference point relative to said high side of said bent sub assembly; and
(ii) providing said determined angular offset to a software program to permit said software program to then correct angular directional orientation sensed by said directional sensor by said angular offset to indicate a correct bent sub angular orientation.
5. A bottom hole assembly for use in directional drilling, comprising:
(i) a housing member containing a directional sensor for sensing orientation of the drill string;
(ii) a bent sub assembly threadably coupled indirectly or directly to said housing member;
(iii) a series of graduated markings circumferentially applied on said bent sub assembly in known angular relationship to a high side of said bent sub assembly, wherein numerical values associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said high side angular location of said bent sub and increase progressively negatively in an opposite angular direction from said zero position, and
(b) a reference marking on said housing member indicative of said directional sensor reference point.
or
(a) series of graduated markings applied on an outer surface of a housing member containing said directional sensor, wherein numerical values associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said reference point and increase progressively negatively in an opposite angular direction from said zero position, and
(b) a reference marking applied on said bent sub assembly indicative of bent sub high side angular location;
6. An orienting sub for use in directional drilling, comprising:
(i) a housing member containing a directional sensor for sensing orientation of the drill string, said directional sensor fixedly secured to said housing member sub in known angular relation to said graduated markings thereon; and
(ii) a series of graduated markings applied circumferentially on an outer surface of a housing member containing said directional sensor, wherein numerical values associated with said graduated markings increase progressively positively in an angular direction from a zero position indicative of said reference point and increase progressively negatively in an opposite angular direction from said zero position, adapted to allow determination of angular offset of said directional sensor reference point relative to said high side of said bent sub assembly.
7. An bent sub assembly for use in directional drilling, comprising:
(i) thread coupling means to allow threadable coupling to an orienting sub containing a directional sensor;
(ii) a series of graduated markings applied circumferentially on an outer surface of said bent sub assembly, wherein numerical graduations associated with said graduated values increase progressively positively in an angular direction from a zero position indicative of a high side of said bent sub and increase progressively negatively in an opposite angular direction from said zero position, adapted to allow determination of angular offset of said high side from an orienting directional sensor reference point on said orienting sub when threadably connected thereto.
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